APPLICATION OF COHERENT TUNE SHIFT MEASUREMENTS TO THE CHARACTERIZATION OF ELECTRON CLOUD GROWTH*

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Abstract

Measurements of coherent tune shifts at the Cornell Electron Storage Ring Test Accelerator (CesrTA) have been made for electron and positron beams under a wide variety of beam energies, bunch charge, and bunch train configurations. Comparing the observed tunes with the predictions of several electron cloud simulation programs allows the evaluation of important parameters in these models. These simulations will be used to predict the behavior of the electron cloud in damping rings for future linear colliders. We outline recent improvements to the analysis techniques that should improve the fidelity of the modeling.

INTRODUCTION

When synchrotron radiation from a particle beam hits the vacuum chamber of a storage ring, the produced photoelectrons can set up a persistent electron cloud. The focusing effect experienced by a subsequent bunch passing through that cloud results in a betatron tune shift for the bunch. By measuring the relative tunes of individual bunches in a bunch train, we can probe the growth of the cloud along the train. As part of the CesrTA research program, we are employing this effect to characterize the ring-wide buildup of the cloud, which forms an important reference point for our beam instability studies. A systematic comparison of the observed tune shifts as a function of bunch spacing, bunch species, and train configurations can also constrain the physics models and model parameters utilized in our cloud growth simulations. By validating the details of the models in this way, we will be able to improve our projections for the performance of future high intensity positron rings such as linear collider damping rings.

THE METHOD

Bunch trains are set into oscillation by displacing them horizontally or vertically with a one-turn kicker. By gating the beam position monitors with the time of passage of individual bunches, we measure the turn-by-turn positions of individual bunches in a train. Typically we follow the motion for 1024 turns, and then Fourier transform to obtain the bunch-by-bunch tunes.

Simulations are performed with POSINST[1] and compared to the measured tunes. In simulating the ring-averaged tune shifts, we ignore the electron cloud buildup in all ring elements except the drift regions and the dipoles. For the photon intensity, we use the calculated number of synchrotron-radiated photons directly striking the vacuum chamber, weighted by beta values[2]. The parameters we vary in the simulation are total secondary electron yield, energy at which the yield is maximal, elastic secondary electron yield, yield of rediffused secondary electrons, quantum efficiency for photoelectron production, and the fraction of photons reflected.

Comparisons of measurements with simulations are made for 54 data runs with electron and positron beams at 1.9, 2.1, 4.0, and 5.3 GeV energy, in trains of 3 to 45 bunches, with bunch charges of 0.5 to 4.2 nC. A reference parameter set has been established based on measured secondary emission parameters for CESR's aluminum vacuum chamber and approximate estimates of quantum efficiency (0.12) and photon reflectivity (15%) based on study of a single data set. All six parameters are varied ~±10% relative to the reference parameter set, individually and in selected pairs. As an example, shown in figure 1 are data (in black) for a 21-bunch train with 1.3 nC of positrons per bunch at 2.1 GeV followed by 12 witness bunches. Three different POSINST simulations are shown in color.

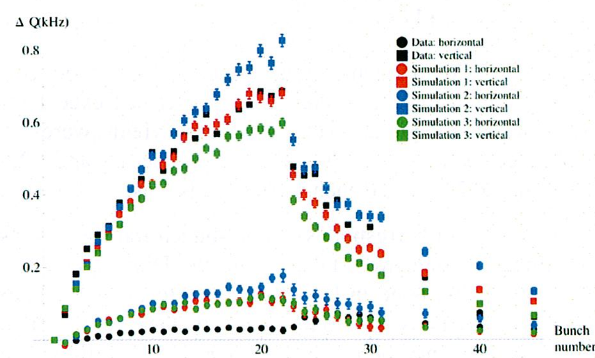

Figure 1: An example of fits to data achieved with the reference parameter set, except for different values of the total secondary yield. Black points are data, colored are simulations. Each bunch contained 1.3 nC of positrons. Bunch separation is 14 ns. The three different simulations (1, 2, 3) correspond to the values (2.0, 2.2, 1.8) for the total secondary yield.

The data-simulation comparisons did not lead to a parameter set significantly improved over the reference set because of the difficulty in finding an optimum in a 6-dimensional space when some of the parameters are highly correlated and the error bars on the data are not

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reliably determined. We are now attempting to improve various aspects of the data (see the next section) and the simulation (in subsequent sections). More precise determinations of the parameters will allow more reliable predictions for ILC damping ring behavior. The subsequent sections describe areas currently under development.

IMPROVEMENTS TO MEASUREMENTS

Beam position measurements made under a variety of beam conditions are of varying quality. For the quantitative data/simulation comparisons needed to evaluate parameters, it is vital both to have accurate measurements and to reliably estimate their errors. New code employs a merge-sort algorithm to both improve the derived tune shifts and better assess their believability.

Most of the data recorded to date were taken with 14 ns spacing between bunches. An exception is shown in Fig. 2.

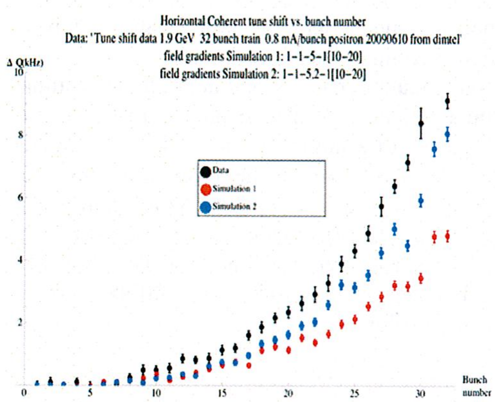

Figure 2: Comparison between data (black), and two simulations using the reference parameter set, except for total secondary yield. Total secondary yields were the reference value 2.0 (simulation 1, red), and 2.2 (simulation 2, blue). Bunch separation is 4 ns.

This data set corresponds to a 32-bunch train with 4 ns spacing. The data were taken using the Dimtel feedback system, as discussed in [3]. They seem to favor a higher total secondary yield than most of the 14 ns data. However, the method of beam excitation was different in the two cases and possible systematic differences still need to be understood.

Clearly, to separate the effects of primary photoelectrons from those of secondaries, it is very useful to study a variety of bunch spacings. Additional data have been taken with 4-, 8-, 12-, and 16-ns spacing, but unfortunately, the results have proven difficult to interpret. It is hoped that the more advanced analysis techniques mentioned above will allow us to interpret these data. Further measurements are planned as needed.

3D MODELING OF PHOTON PROPAGATION AND ABSORPTION

The simulations described above use the photon intensities corresponding to the synchrotron-radiated photons directly striking the vacuum chamber, together with a single empirically determined parameter to describe the reflected photons. However, since the source of the synchrotron radiation is well known, and the reflection of the radiation from the walls can be well characterized, it is possible to make reliable estimates of both the direct and scattered radiation. These estimates allow a full characterization of the radiation absorbed on the walls to be made, without the need for an empirically determined reflectivity parameter. Since the radiation characterization can be made for any beam energy, ring lattice, and vacuum chamber profile, this greatly facilitates the extrapolation of electron cloud buildup calculations to future positron rings.

A new code Synrad3D[4] has been developed to do the radiation calculations. The code uses the full three-dimensional chamber geometry and ring lattice to obtain both the intensity and the angular distribution of the synchrotron radiation hitting the chamber walls. The output of Synrad3D can be read into POSINST to provide a fully characterized description of the incident radiation. The description is limited by the accuracy of the vacuum chamber model, and by the approximations used in the scattering model. To date, the radiation calculations have been done with a simple, longitudinally uniform, vacuum chamber model, and with a scattering model based on purely specular reflection from an aluminum surface. However, the code has the capability to model complex vacuum chamber shapes and to include diffuse scattering.

Fig. 3 exhibits the results of a simulation using the Synrad3D radiation distributions, for the same data shown in Fig. 1. To improve the fit, new reference photoelectron parameters (quantum efficiency of 0.108 for dipoles and 0.097 for drifts), and a Lorentzian photoelectron energy spectrum, with parameters similar to those reported in [5]) have been used. Note the improved agreement for the rather small horizontal tune shifts, compared to Fig. 1.

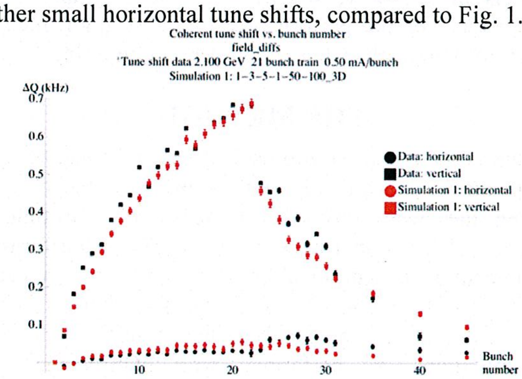

Figure 3: Comparison between the same data as Fig. 1 and a new simulation with radiation distributions from Synrad3D, and new reference photoelectron parameters as described in the text. Black points are data, red are simulation. The total secondary yield was 2.0.

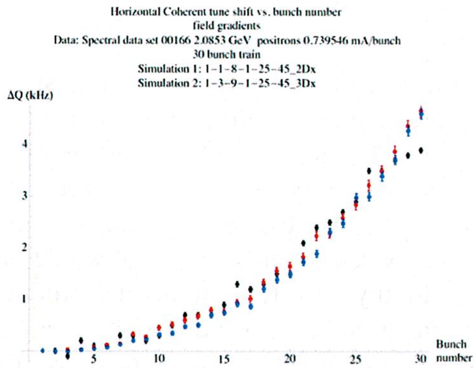

Figure 4: Comparison between data (black), simulation using reference parameter set, with total secondary yield 2.05 (red), and simulation using radiation distributions from Synrad3D, new reference photoelectron parameters, and total secondary yield 2.10 (blue).

Another example of a comparison between data, simulations using the original reference parameters, and simulations based on Synrad3D with new photoelectron parameters, is shown in Fig. 4. In this case, the data correspond to self-excited tune shift measurements made in connection with beam instability measurements, as described in [3]. Fig. 4 suggests that, for the Synrad3D simulation, a slightly higher value of the secondary yield is preferred, although further study with improved parameter estimates may change this impression.

QUANTUM EFFICIENCY AND PHOTOELECTRON ENERGY SPECTRUM

In connection with studies of electron cloud effects for the LHC, direct measurements [5] have been made of the quantum efficiency, and the photoelectron energy spectrum, for VUV photons in the energy range up to about 100 eV. The measurements were made for a variety of surfaces, including aluminum, which is relevant for the CesrTA vacuum chamber.

The relative quantum efficiency was measured as a function of photon energy. This information can be combined with the energy spectrum of absorbed photons, which is provided by the Synrad3D code, to estimate how the quantum efficiency might be expected vary for different beam energies, and at different points in the CesrTA ring. This provides additional information that is useful in constraining electron cloud parameters when comparing with data, and in extrapolating electron cloud effects to future positron rings.

Absolute quantum efficiencies, averaged over a VUV photon energy spectrum, were also measured in reference [5]. These results were quite sensitive to the surface material and condition, but were in the range of 0.041 to 0.106. Quantum efficiency values found for the best fits to the CesrTA tune shift data are in this same range.

The measurements in reference [5] indicate that the photoelectron energy spectrum can be well represented by a Lorentzian with a peak and width of a few eV. Studies of the shielded button data (described in [6]) demonstrate that, although a simple Lorentzian distribution is adequate for the photons generated by a 2 GeV CesrTA beam, for the harder photon spectrum generated by a 5 GeV beam, a high-energy tail, with a power law falloff slower than that of a Lorentzian, is required. Consequently, a new parameterization, using a Lorentzian spliced to a power law distribution with an adjustable exponent at high photoelectron energies, has been installed in POSINST. Preliminary re-evaluation of the tune shift simulations for both positron and electron beams at 5 GeV indicate that the high energy tail in the photoelectron energy spectrum makes only small differences in the simulated tune shifts.

FUTURE WORK

Using the Synrad3D radiation distributions, and the improved photoelectron model described above, the existing body of CesrTA tune shift data will be re-analyzed to extract more precise information about the electron cloud model parameters, and to test the validity of the model across a wide range of beam conditions. This will allow more reliable predictions for ILC damping ring behavior.

REFERENCES

[1] M. Furman and G. Lambertson, "The electron-cloud instability in the arcs of the PEP-II positron ring," http://repositories.cdlib.org/lbnl/LBNL-41123.
M. A. Furman and M. T. F. Pivi, Probabilistic Model for the Simulation of Secondary Electron Emission, Phys. Rev. ST-AB 5, 124404 (2002).

[2] G. F. Dugan, M. A. Palmer, and D. L. Rubin, ILC Damping Rings R&D at CesrTA, ICFA Beam Dynamics Newsletter No. 50, eds. J. Urakawa and W. Chou (2009).
J. A. Crittenden, *et al.*, Studies of the Effects of Electron Cloud Formation on Beam Dynamics at CesrTA, proceedings of PAC09, 4-8 May 2009, Vancouver, British Columbia, Canada.

[3] M. Billing, *et al.*, "Measurement Techniques to Characterize Instabilities caused by Electron Clouds," contribution to this conference.

[4] G. Dugan, and D. Sagan, "Synrad3D Photon propagation and scattering simulation", contribution to this workshop.

[5] Cimino, Collins, Baglin, VUV photoemission studies of candidate LHC vacuum chamber materials, PRSTAB 2,063201 (1999)

[6] J. Crittenden et. al., contribution to this conference